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Ictalurid Populations in Relation to the Presence of a Main-Stem Reservoir in a Midwestern Warmwater Stream with Emphasis on the Threatened Neosho Madtom

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Abstract.—Ictalurid populations, including those of the Neosho madtom *Noturus placidus*, have been monitored in the Neosho River basin since the U.S. Fish and Wildlife Service listed the Neosho madtom as threatened in 1991. The Neosho madtom presently occurs only in the Neosho River basin, whose hydrologic regime, physical habitat, and water quality have been altered by the construction and operation of reservoirs. Our objective was to assess changes in ictalurid densities, habitat, water quality, and hydrology in relation to the presence of a main-stem reservoir in the Neosho River basin. Study sites were characterized using habitat quality as measured by substrate size, water quality as measured by standard physicochemical measures, and indicators of hydrologic alteration (IHA) as calculated from stream gauge information from the U.S. Geological Survey. Site estimates of ictalurid densities were collected by the U.S. Fish and Wildlife Service annually from 1991 to 1998, with the exception of 1993. Water quality and habitat measurements documented reduced turbidity and altered substrate composition in the Neosho River basin below John Redmond Dam. The effects of the dam on flow were indicated by changes in the short- and long-term minimum and maximum flows. Positive correlations between observed Neosho madtom densities and increases in minimum flow suggest that increased minimum flows could be used to enhance Neosho madtom populations. Positive correlations between Neosho madtom densities and increased flows in the winter and spring months as well as the date of the 1-d annual minimum flow indicate the potential importance of the timing of increased flows to Neosho madtoms. Because of the positive relationships that we found between the densities of Neosho madtoms and those of channel catfish *Ictalurus punctatus*, stonecats *Noturus flavus*, and other catfishes, alterations in flow that benefit Neosho madtom populations will probably benefit other members of the benthic fish community of the Neosho River.

Reservoirs decrease the flow of sediments and alter the hydrologic regime, physical habitat, and water quality downstream (Obeng 1981; Stanford et al. 1996). Hesse and Mestl (1993) showed that a reservoir system can substantially alter the hydrograph of a river system. Patton and Hubert (1993) found that the presence of a reservoir on a Great Plains stream eliminated braided channels

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that had historically existed downstream. After the construction of an extensive reservoir system within the lower Kansas River, the range of flow was reduced, turbidity declined, phytoplankton increased, and substrate changed from loose and "quick" to firm and stable (Cross and Moss 1987).

Cross and Moss (1987) suggested that the changes in hydrology and habitat that result from water control by dams and reservoirs have detrimental impacts on fish populations. Subsequent research has demonstrated this (Bain et al. 1988; Scheidegger and Bain 1995). Cross and Moss compared predam and postdam data to show the impact of the reservoirs in the Arkansas River system on fish communities, flows, and turbidity. Frequent extreme variations in hourly water flow caused by a hydroelectric dam have been shown to reduce the abundance of habitat specialists (i.e., fish species that strongly prefer shallow, slow water along stream margins; Bain et al. 1988), lower abundance in the larval fish community (Scheidegger and Bain 1995), and result in a downstream recovery gradient of the fish community (Niemi et al. 1990; Yount and Niemi 1990; Kinsolving and Bain 1993). One might expect the impacts that flood control dams have on downstream riverine ecosystems to be similar to those of hydroelectric dams because of the regulated nature of both systems. However, the effects of hydroelectric dams should be larger and more immediate than those of flood control dams owing to the higher frequency of changes in flow associated with the former (Baxter 1985). Our study focuses on a dam-and-reservoir system designed primarily for flood control.

One of the most recently developed methods for evaluating how the hydrology of a river system has changed over time is known as indicators of hydrologic alteration (IHA; Richter et al. 1996; The Nature Conservancy 1997). IHA is a series of different annual measures calculated from the stream gauge data for each water year (October 1 of the year before to September 30 of the current year) that are available from the U.S. Geological Survey (USGS). The IHA measures include the average daily discharge for each of the 12 months; the average minimum and maximum daily discharges over 1, 3, 7, 30, and 90 d; the days of the year of the 1-d minimum and maximum discharges; the number of reversals between rising and falling discharges and the mean rate of rising and falling discharges; and the number of low pulses and high pulses and their average length in days. These measures help to characterize the hydrologic variation of a stream system within each year. The goal of Richter et al. (1996) was to provide an analytical tool for describing complex hydrologic variation to facilitate investigation of the ecosystem effects of hydrologic alterations. The hydrologic measures developed by Richter et al. were guided by the paradigm that the most effective way to manage riverine ecosystems is to protect or restore "natural" hydrologic regimes (Sparks 1992; Poff et al. 1997). By trying to maintain or restore the natural hydrologic regime, resource managers should be able to maintain or restore the entire group of species in a riverine ecosystem (Sparks 1992).

The Neosho madtom *Noturus placidus* (Taylor 1969) is a small (<75 mm total length) ictalurid that is native to the main stems of the Neosho and Cottonwood rivers in Kansas and Oklahoma and the Spring River in Kansas and Missouri (Luttrell et al. 1992; Cross and Collins 1995; Wilkinson et al. 1996). This species occupies portions of riffles with mean flows of 79 cm/s, mean depths of 0.23 m, and unconsolidated pieces of pebble and gravel 2–64 mm in diameter (Moss 1983). Neosho madtoms feed at night on larval insects found among the gravel (Cross and Collins 1995). Based on samples collected throughout the year (both day and night), the highest numbers of Neosho madtoms occur in riffles during daylight hours in late summer and early fall after young of year are believed to have recruited to the population (Moss 1983; Luttrell et al. 1992; Fuselier and Edds 1994). Previous research suggests that Neosho madtoms have a life cycle that is annual in nature, with recruitment of young of year into adult collection gear about the time the adults begin to disappear from collections (Fuselier and Edds 1994).

Downstream of its confluence with the Cottonwood River, the Neosho River is regulated by John Redmond Dam, which forms John Redmond Reservoir, a body of water that is used for flood control, water supply, maintenance of downstream water quality, and recreation (Figure 1). The Neosho madtom was federally listed as threatened by the U.S. Fish and Wildlife Service (USFWS) in May 1990, and a recovery plan was approved in September 1991 (USFWS 1991). The plan suggested the need for maintaining springtime flows for spawning as well as minimum flows during low-water times for the survival of Neosho madtom populations.

Our objective was to assess the impact of the presence and operation of John Redmond Dam and Reservoir on ictalurid population trends (in par-

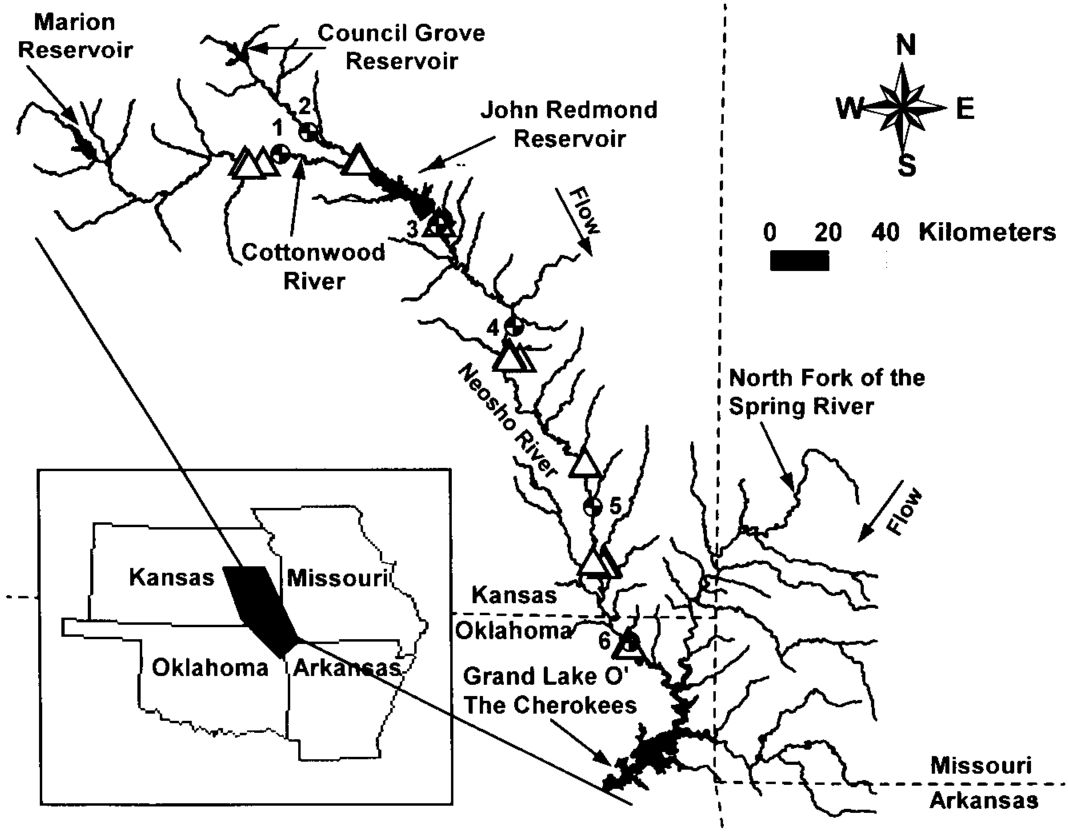

FIGURE 1.—Sampling sites (triangles) on the Neosho and Cottonwood rivers from 1991 to 1998. U.S. Geological Survey gauging stations are represented by half-filled circles. Numbers represent locations as follows: 1 = Plymouth, Kansas; 2 = Americus, Kansas; 3 = Burlington, Kansas; 4 = Iola, Kansas; 5 = Parsons, Kansas; and 6 = Commerce, Oklahoma.

ticular those of the Neosho madtom), as well as on the hydrology, habitat, and water quality in the Neosho River. Specifically, our hypothesis was that the presence of John Redmond Dam has significantly changed the hydrology, habitat, and water quality in the Neosho River below the dam and thus is detrimentally affecting ictalurid populations, particularly those of the Neosho madtom. We tested this hypothesis by comparing the following: (1) current ictalurid densities, habitat, and water quality above the reservoir and those below the dam; (2) predam and postdam hydrographs for the Neosho River below the dam; (3) postdam hydrographs above the reservoir and those below the dam; and (4) the relationships between annual ictalurid densities and the current and preceding water year values of each IHA measure.

Study Area

The study area included the main stems of the Neosho and Cottonwood rivers in Kansas and Oklahoma, which we will refer to as the Neosho River basin (Figure 1). The Neosho and Cottonwood rivers are part of the Arkansas River drainage and drain mainly tallgrass and mixed-grass prairie, with mature riparian vegetation along some sections (Moss 1983). The Cottonwood River joins the Neosho River near Emporia, Kansas. The Cottonwood River and the Neosho River upstream of its confluence with the Cottonwood River are fifth-order streams (Moss 1983), with mean annual discharges from 1990 to 1998 of 25.0 m^3/s at Plymouth, Kansas, and 12.7 m^3/s at Americus, Kansas, respectively (Figure 1). The headwaters of the Neosho and Cottonwood rivers are regulated by reservoirs. Construction of Marion Reservoir at the headwaters of the Cottonwood River began in 1964, with embankment closure in 1967 and full flood control operation in 1968 (Tulsa District USACE 1993). Construction of Council Grove Lake at the headwaters of the Neosho River began in 1960, and the lake was placed in full flood control operation in 1964 (Tulsa District USACE 1993). Downstream of its confluence with the Cottonwood River, the Neosho River is regulated by John Redmond Dam, construction of which began in 1959, with embankment closure in 1963, full flood control operation in 1964, and final completion in 1965 (Tulsa District USACE 1993). All three reservoirs were constructed with water storage capacity that could be used for flood control, water supply, maintenance of downstream water quality, and recreation (Tulsa District USACE 1993).

Methods

Gravel bar sampling.—From 1991 to 1998, 12 gravel bars (shoreline collections of pebbles up to 38 mm in diameter that extend out into the river and are believed to provide suitable habitat for Neosho madtoms) were selected by USFWS for monitoring Neosho madtom populations (USFWS 1991). Generally, the same gravel bars, or ones in the same river reaches, were sampled each year (Figure 1). The number of sites sampled above John Redmond Reservoir and below John Redmond Dam was similar but varied somewhat owing to high-water conditions and shifting gravel bars. Sampling at all sites occurred during daylight hours between August and October, after Neosho madtom young-of-year recruitment was expected to have occurred. In 1993, no sampling was possible owing to extreme flooding. Data from 1996 were excluded from analyses because only four sites, all above the reservoir, were sampled owing to inaccessibility resulting from high waters.

Before sampling, three to five transects perpendicular to the river channel were spaced equally to span the length of the bar. In most instances, five stations were spaced equally along each transect, with a minimum distance of 2 m between adjacent stations. Fewer than five stations were established if the river channel was less than 10 m wide or if a station occurred at a depth too great to seine (>1.25 m). Transects on a gravel bar were sampled in order from downstream to upstream. On each transect, stations were sampled in order from nearest to most distant from the gravel bar. At each station, sampling proceeded in the following order to minimize the impacts of samples on each other: ictalurids (Neosho madtom, channel catfish *Ictalurus punctatus*, slender madtom *Noturus exilis*, stonecat *N. flavus*, brindled madtom *N. miurus*, freckled madtom *N. nocturnus*, and flathead catfish *Pylodictis olivaris*), substrate, water depth, water velocity, and surface water. Measurements of substrate and surface water quality were collected only in 1991. Fishes were collected from a 4.5-m^2 area by disturbing the substrate starting 3 m upstream of a stationary seine (3.0-mm^2 mesh) and proceeding downstream to the seine (i.e., kick-seining). All ictalurids were identified, measured for total length, and released back into the river. Substrate was collected from an undisturbed area adjacent to the fish sampling location with a 13-cm deep × 10-cm-diameter cylindrical grab sampler. Substrate samples were placed in plastic bags, transported to the laboratory, dried for 10–15 min at 100–110°C, and sieved into five size-classes (<2 mm, 2–9 mm, 9–19 mm, 19–38 mm, and > 38 mm) that were then weighed. Water depth was recorded, and water velocity at 60% of water depth was measured with a Marsh-McBirney model 201 current meter. After all station samples were collected at a site, a surface water sample was analyzed with a Hach model DREL/1C portable colorimeter for pH, alkalinity, hardness, conductivity, turbidity, un-ionized ammonia (NH_3), nitrite plus nitrate (NO_2 + NO_3), sulfate (SO_4), phosphate (PO_4), and chloride (Cl^-).

Hydrologic data.—We obtained USGS hydrologic data in the form of daily mean flows from gauges on the Neosho and Cottonwood rivers before and after the construction of John Redmond Dam. The 1960s was the decade of ongoing reservoir construction; full flood control operation was not in effect for all three primary reservoirs combined (Council Groves, John Redmond, and Marion) until 1968 (Tulsa District USACE 1993). Therefore, the postconstruction hydrograph for the period prior to the initiation of Neosho madtom population monitoring was represented by data from water years 1970 to 1989 (1970 is the water year that started in October 1969). This supplied the 20-year minimum data set suggested by Richter et al. (1997) for representation of the postconstruction period. We used hydrologic data from 1940 to 1959 to represent the 20-year preconstruction hydrograph needed for comparison with the postconstruction hydrograph. We used 1990–1998 hydrographic data from the gauges at Americus, Plymouth, Burlington, Iola, and Parsons, Kansas, and Commerce, Oklahoma (Figure 1), to directly test relationships among IHA measures and Neosho madtom densities.

We used predam and postdam data from the gauge near Iola, Kansas, to compare the hydrograph of the Neosho River below John Redmond Dam before and after the construction of the three primary reservoirs in the Neosho River basin (Figure 1). The gauge at Iola was the closest one downstream of John Redmond Dam (89 km) that was in operation before construction of the three reservoirs (Putnam et al. 1996).

We used postdam hydrologic data from the gauges near Americus and Burlington, Kansas, on the Neosho River and Plymouth, Kansas, on the Cottonwood River to more directly assess the effects of John Redmond Dam on the hydrograph of the Neosho River. The gauge near Americus is 38.6 km upstream of the mouth of the Cottonwood River. The gauge near Plymouth is 63.1 km upstream of the confluence with the Neosho River. The Americus and Plymouth gauges are the nearest ones upstream of John Redmond Reservoir. There are no gauges between the confluence of the Neosho and Cottonwood rivers and the reservoir. Because the hydrologic data used consisted of daily means, the data from the Americus and Plymouth gauges could be considered synchronized. Therefore, as a conservative estimate, we combined the hydrologic data from these two gauges to represent the postdam Neosho River hydrograph above the reservoir. Data from the gauge near Burlington were used to represent the postdam Neosho River hydrograph below John Redmond Dam because that gauge is much closer to the dam (8.5 km downstream) than the one near Iola.

Statistical analyses.—We analyzed the physical, chemical, and fish population data to assess differences between sites above John Redmond Reservoir and sites below John Redmond Dam as well as differences across years. Arithmetic means were calculated for sites' depth and velocity. We calculated site densities for four categories of fish: Neosho madtoms, channel catfish, stonecats, and all non-Neosho madtoms ictalurids combined. The last grouping was established because some species of ictalurids were not found often enough to allow separate species-level analyses. We calculated fish densities by dividing the total number of Neosho madtoms, all other catfishes combined, channel catfish, stonecats, and other catfishes collected at a site by the total area sampled by kick-seining. We calculated site means for substrate size categories by dividing the total weight of a size category by the total weight of all size categories for the site. We also calculated the geometric mean and fredle index (geometric mean adjusted for distribution of particle sizes) for the substrate at each site, as suggested by McMahon et al. (1996), to characterize substrate suitability for Neosho madtoms. When the geometric means of substrate samples are similar, a high fredle index indicates substrate consisting largely of sizes near the mean, while a low fredle index indicates more evenly distributed substrate sizes. The fredle index is positively correlated with the potential permeability of sediment to water, and hence to dissolved oxygen transport within the sediment, and it has been shown to be positively correlated with the emergence of salmonid alevins (Platts et al. 1983 and references therein). Mean daily flow data were summarized before analysis by means of IHA measure estimates produced with the IHA software (Nature Conservancy 1997).

All statistical tests were conducted using SAS software (SAS Institute 1990). Site means were checked for normality and tested for homogeneity of variance using a chi-square test (Steel and Torrie 1980). Most nonnormal variables were $\log_{10}$ transformed; variables that were proportions or ratios were transformed using the arcsine of the square root. Various statistical methods were used to make primary comparisons between the situation before and after dam construction; between the situation above John Redmond Reservoir and that below John Redmond Dam; among Neosho madtom densities and ictalurid densities, depth, and velocity; and among the IHA measures and Neosho madtom densities. These methods included analysis of variance (ANOVA), Levene's test for differences in variance, correlation analysis, and analysis of covariance (ANCOVA) (SAS Institute 1990). Generally, relationships for which $P < 0.05$ were considered significant and those for which $0.05 \leq P < 0.10$ were considered marginally significant. Separate two-way ANOVAs with years and location above the reservoir or below the dam were performed on site means for fish densities, depth, and velocity. Separate one-way ANOVAs were performed on the annual IHA values for comparisons between the predam and postdam situations and those above the reservoir and below the dam. Our ability to normalize variables through transformations and equal sample sizes allowed us to use the power and robustness of ANOVA to test hydrologic differences in mean values relative to location above the reservoir or below the dam despite the differences in variance that may have existed (Milliken and Johnson 1984). Because Richter et al. (1997) emphasized the importance of the interannual variation in IHA measures to a riverine ecosystem—along with the central tendencies of those measures—we also used Levene's test to assess the effects of the presence of the dam on interannual variation in the IHA measures.

Correlation analyses were used to assess relationships between the densities of Neosho madtoms, all other catfishes combined, channel catfish, and stonecats and depth and velocity. Separate two-way ANCOVAs were performed on Neosho madtom densities for each IHA measure to assess the relationships between Neosho madtom densities and IHA measures after adjusting for effects attributable to year and position relative to the dam and reservoir. The above-the-reservoir versus below-the-dam effect in the ANCOVA models accounted for relationships that were the result of upstream–downstream patterns resulting from potentially important factors such as stream size and the presence of the dam and reservoir. The ultimate goal of the ANCOVAs was to determine if Neosho madtom population trends were related to IHA measures independent of the two main factors present within the design of the study (i.e., year and presence of the dam and reservoir). For the ANCOVAs, we used current and preceding water years for the gauge closest to the gravel bar sampled. Because there were fewer gauges than there were gravel bars sampled, we grouped gravel bars by nearest gauge (i.e., Plymouth, Americus, Plymouth and Americus combined, Burlington, Iola, Parsons, or Commerce). We then averaged Neosho madtom site densities in each year by gauge grouping before any ANCOVAs were conducted. The annual nature of the life cycle of the Neosho madtom made it possible for us to compare density relationships with IHA measures in the current and preceding water years to assess whether population trends were the result of survival to reproductive age (or reproductive success) and survival of young of year to recruitment to the population, respectively.

Before we present our results, two important points need to be made concerning the validity and strength of those results as they relate to the analyses chosen. First, if it had been possible, this study should have been done in the context of a before-after-control-impact-pairs (BACIP) design (Stewart-Oaten et al. 1992). In the BACIP design, the system is studied before and after the impact (in this case dam construction) simultaneously with a control system to ensure that observed changes are the result of the impact and not some unknown environmental factor. Because the Neosho madtom was not identified as a species until after construction of the dam (Taylor 1969; Tulsa District USACE 1993), a before–after comparison of fish populations was not possible. Owing to the regional nature of the distribution of Neosho madtom populations (Luttrell et al. 1992; Cross and Collins 1995; Wilkinson et al. 1996), a control system for comparison is not available for the species. Even so, the validity of the information gained from this study is supported by the length of time covered, which provided data over an 8-year period for a fish that generally lives 2 years or less (Fuselier and Edds 1994). In essence, the multiyear nature of the study and the Neosho madtom's annual life cycle allow year to be used in ANOVA and ANCOVA models as the control and before–after comparison by accounting for year-to-year variability stemming from unknown environmental factors. Second, the Neosho madtom's annual life cycle results in recruitment of young of year into adult collection gear about the time adults begin to disappear from collections (Fuselier and Edds 1994); as a result, we could not effectively compare young of year and adult Neosho madtoms.

Results

The densities of Neosho madtoms and channel catfish were greater above John Redmond Reservoir than below John Redmond Dam; the density of the all catfishes other than Neosho madtoms was marginally greater above the reservoir; and the densities of stonecats did not differ significantly between the two locations (Table 1). None of the measured catfish densities differed among years. Neosho madtom densities were positively correlated with the densities of all other catfishes combined (r = 0.41, P = 0.001), channel catfish (r = 0.34, P = 0.007), and stonecats (r = 0.35, P = 0.006). Neosho madtom and stonecat densities were positively correlated with water velocity (r = 0.33, P = 0.008; and r = 0.50, P = 0.0001, respectively). The densities of all other catfishes combined, channel catfish, and stonecats were negatively correlated with depth (r = −0.47, P = 0.001; r = −0.33, P = 0.001; and r = −0.51, P = 0.0001). The negative correlation between Neosho madtom densities and depth was marginally significant (r = −0.22, P = 0.08). In all of the above correlations, N = 61.

Physical habitat and water quality characteristics differed above John Redmond Reservoir and below John Redmond Dam (Table 2). Turbidity was higher, water temperature lower, and the fredle index marginally lower above the reservoir (Table 2). Water depth was marginally lower above the reservoir (Table 1). Water velocity, individual substrate size-classes, and the geometric mean of substrate size did not differ between the two locations

TABLE 1.—Two-way analysis of variance (ANOVA) results for 1991–1998 ictalurid densities, water depth, and velocity among years and location above John Redmond Reservoir or below John Redmond Dam.

Variable	Density (fish per 100 m^2) Neosho madtoms	Catfishes other than Neosho madtoms	Channel catfish	Stonecats	Depth (m)	Velocity (m/s)
			Two-way ANOVA (P-value [F])			
Year	0.15	0.45	0.28	0.33	0.36	0.013
	[1.69]	[0.97]	[1.29]	[1.18]	[1.13]	[3.24]
Location	0.0015	0.066	0.051	0.44	0.070	0.71
	[11.31]	[3.53]	[4.01]	[0.60]	[3.44]	[0.14]
Year × location	0.29	0.089	0.071	0.53	0.93	0.95
	[1.28]	[2.05]	[2.19]	[0.83]	[0.26]	[0.21]
			Means			
Neosho and Cottonwood rivers above John Redmond Reservoir	19.82	45.40	34.31	4.61	0.33	0.34
Neosho River below John Redmond Dam	5.64	25.66	18.73	2.83	0.38	0.35

(Tables 1 and 2). Dissolved oxygen concentrations, temperature, and PO_4 concentrations were lower (the last marginally), while alkalinity and NH_3 were higher above the reservoir (Table 2). Conductivity, pH, hardness, SO_4, and Cl^- did not differ. The concentration of $NO_2 + NO_3$ was 1.5 mg/L at one site below the dam but 0.23 mg/L or less at all other sites, with six of these sites having nondetectable levels. For this reason, $NO_2 + NO_3$ data were not analyzed statistically and are not reported in Table 2. Water velocity was different among years, but depth was not (Table 1).

Hydrographic data (IHA values) were related to the presence of John Redmond Dam and John Redmond Reservoir (Figures 2–5), and Neosho madtom densities were related to IHA values (Table

TABLE 2.—Means, standard deviations (SD), and one-way analysis of variance (ANOVA) results for 1991 habitat and water quality measurements for locations above John Redmond Reservoir and below John Redmond Dam. For all variables except water quality measures above John Redmond Reservoir $N = 6$; for those measures, $N = 5$.

Variable	Above John Redmond Reservoir Mean	SD	Below John Redmond Dam Mean	SD	P-value (F)
Substrate (percent by weight)					
≥38 mm	4.35	0.11[a]	7.5	0.15[a]	0.38 (0.83)
<38 and ≥19 mm	26.63	12.26	23.26	6.57	0.57 (0.35)
<19 and ≥9 mm	31.47	5.64	36.32	11.00	0.36 (0.92)
<9 and >2 mm	21.54	5.89	19.52	6.03	0.57 (0.35)
<2 mm	15.14	6.75	11.95	5.61	0.39 (0.79)
Geometric mean	10.40	0.06[a]	11.74	0.04[a]	0.50 (0.49)
Fredle index	5.52	1.85	7.82	2.12	0.073 (4.02)
Water quality					
Water temperature (°C)	24.74	1.80	27.58	1.30	0.014 (9.26)
Turbidity (NTU)	57.0	17.89	27.17	7.36	0.0045 (14.09)
pH	8.37	0.07	8.47	0.21	0.37 (0.90)
Dissolved oxygen (mg/L)	4.66	0.67	5.62	0.59	0.033 (6.31)
Conductivity (μmhos/cm)	548.00	189.12	433.33	32.04	0.17 (2.18)
Alkalinity (mg/L)	161.20	9.31	145.00	3.46	0.0032 (15.84)
Hardness (mg/L)	220.92	0.17[b]	180.22	0.02[b]	0.24 (1.59)
NH_3 (mg/L)	0.40	0.05	0.15	0.09	0.0003 (33.15)
SO_4 (mg/L)	65.0	57.12	48.83	6.15	0.50 (0.48)
PO_4 (mg/L)	1.38	0.71	2.43	1.07	0.094 (3.50)
Cl^- (mg/L)	14.20	9.31	13.67	2.88	0.90 (0.02)

[a] Standard deviation of arcsin(proportion$^{1/2}$)-transformed data.
[b] Standard deviation of $\log_{10}$-transformed data.

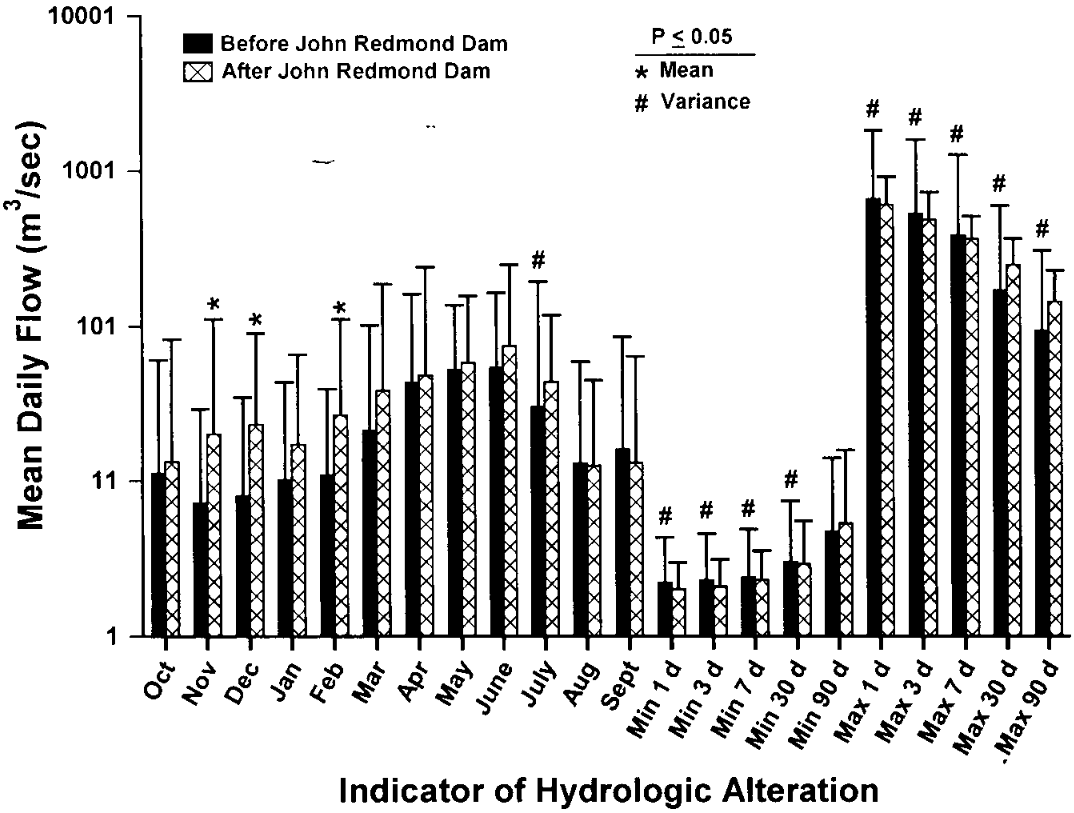

FIGURE 2.—Means and standard deviations for 22 flow indicators before and after construction of John Redmond Dam and John Redmond Reservoir (Richter et al. 1996). The U.S. Geological Survey hydrologic data used are from the gauge near Iola, Kansas. The period 1940–1959 represents the predam period, the period 1970–1989 the postdam period ($N = 20$ in each period). Asterisks indicate significant ($P \leq 0.05$) differences between flows before and after construction of the dam and reservoir; pound signs indicate significant differences in variance. "Min" and "max" refer to minimum and maximum, respectively.

3). The mean February, November, and December flow rates, date of annual maximum flow, and number of reversals between rising and falling water were lower before the construction of the dam (Figures 2 and 3). The variability of the minimum and maximum flows at 1, 3, 7, and 30 d was greater before the construction of the dam, as was that of the 90-d maximum flow and July flow rate (Figure 2); the variability in annual maximum flow date was greater after construction of the dam. The mean minimum flows at 1, 3, 7, and 30 d, along with the 1-d and 3-d maximum flows and the flow rise rate values were all greater above the reservoir (Figures 4 and 5); the 30-d and 90-d maximum flow rates, low-pulse count, and high-pulse duration were lower above the reservoir. The variabilities of the 1-d and 3-d maximum flow rates, low-pulse count, and rise rate of flow were greater above the reservoir (Figures 4 and 5); variability in high-pulse length was lower above the reservoir. The effects of the dam on the minimum and maximum flows of the Neosho River tended to decrease with increasing distance downstream (Figure 6). There was a dramatic decrease in Neosho madtom densities just downstream of the dam near the Burlington gauge (Figure 6). Further downstream, near the Iola gauge, Neosho madtom population densities increased to levels near those found above John Redmond Reservoir. Densities began to decrease again from Iola downstream to Parsons; however, they were still greater than those at Burlington. The ANCOVA of Neosho madtom densities and IHA measures for the current and preceding water years showed significant positive relationships between Neosho madtom density and (1) the minimum flows at 1, 3, 7, 30, and 90 d; (2) the mean daily flows in October, December, January, May, June, and August; and (3) the date

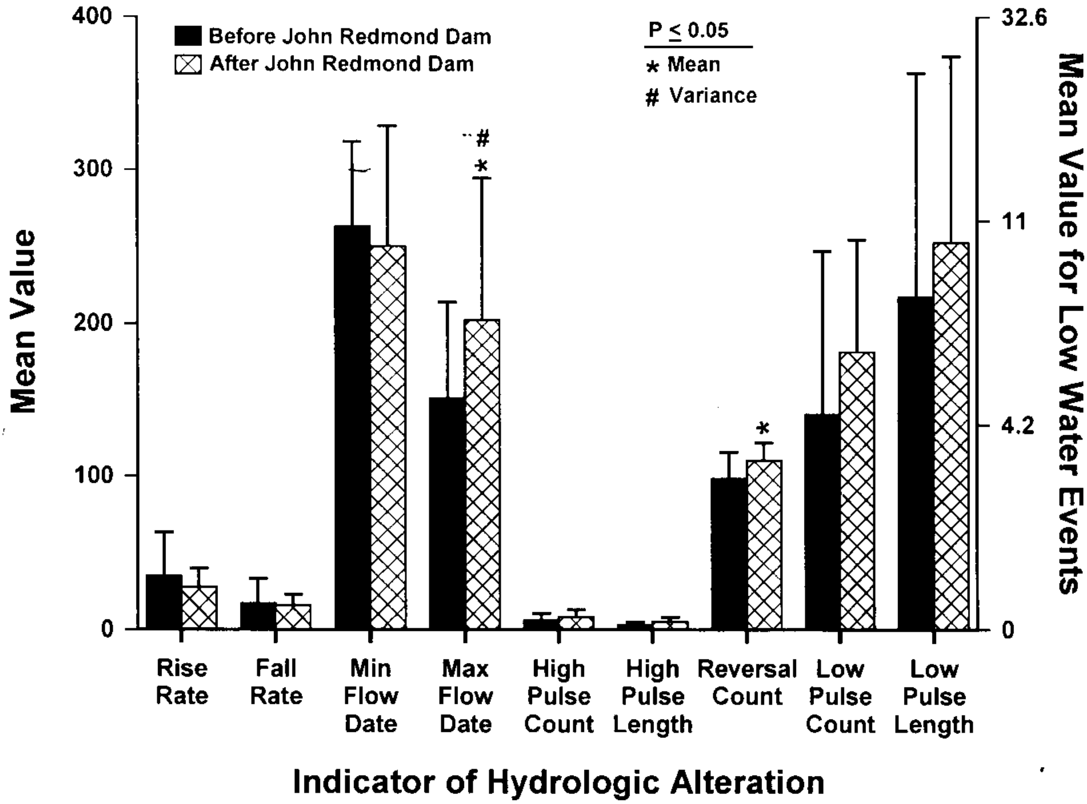

FIGURE 3.—Means and standard deviations for the frequency, duration, and timing of extreme flows as well as the frequency and magnitude of changes in flow rate before and after construction of John Redmond Dam and John Redmond Reservoir (Richter et al. 1996). The U.S. Geological Survey hydrologic data used are from the gauge near Iola, Kansas. The period 1940–1959 represents the predam period, the period 1970–1989 the postdam period (N = 20 in each period). Asterisks indicate significant ($P \leq 0.05$) differences between flow indicators before and after construction of the dam and reservoir; pound signs indicate significant differences in variance. "Min" and "Max" refer to minimum and maximum, respectively.

of the annual minimum daily flow (Table 3). The annual minimum flow occurred around the middle of September.

Discussion

We documented important relationships between location in relation to a main-stem dam and reservoir and ictalurid densities, water quality, substrate size composition, and hydrology. These findings all suggest potential impacts on the ictalurid populations, particularly populations of Neosho madtoms, in the Neosho River as a result of alterations in water quality, the availability of suitable habitat as measured by substrate, and hydrology below John Redmond Dam. Our results are consistent with previous surveys that implicated the construction and operation of John Redmond Dam and John Redmond Reservoir as causes of the changes in the structure of the fish community that have occurred within the upper Neosho River basin (Cross and Braasch 1969). This study helps to define more specifically how and to what extent water quality, habitat as measured by substrate size composition, and hydrology as measured by IHA factors have been altered in the Neosho River basin as an aid to formulating river management strategies to improve the chances for recovery of the ictalurid community within that basin.

The differences in turbidity, the fredle index, water temperature, dissolved oxygen, alkalinity, NH_3, and PO_4 above John Redmond Reservoir versus below John Redmond Dam suggest reservoir impacts on the water and habitat quality of the Neosho River. Changes in turbidity and substrate in the Neosho River below the dam parallel ob-

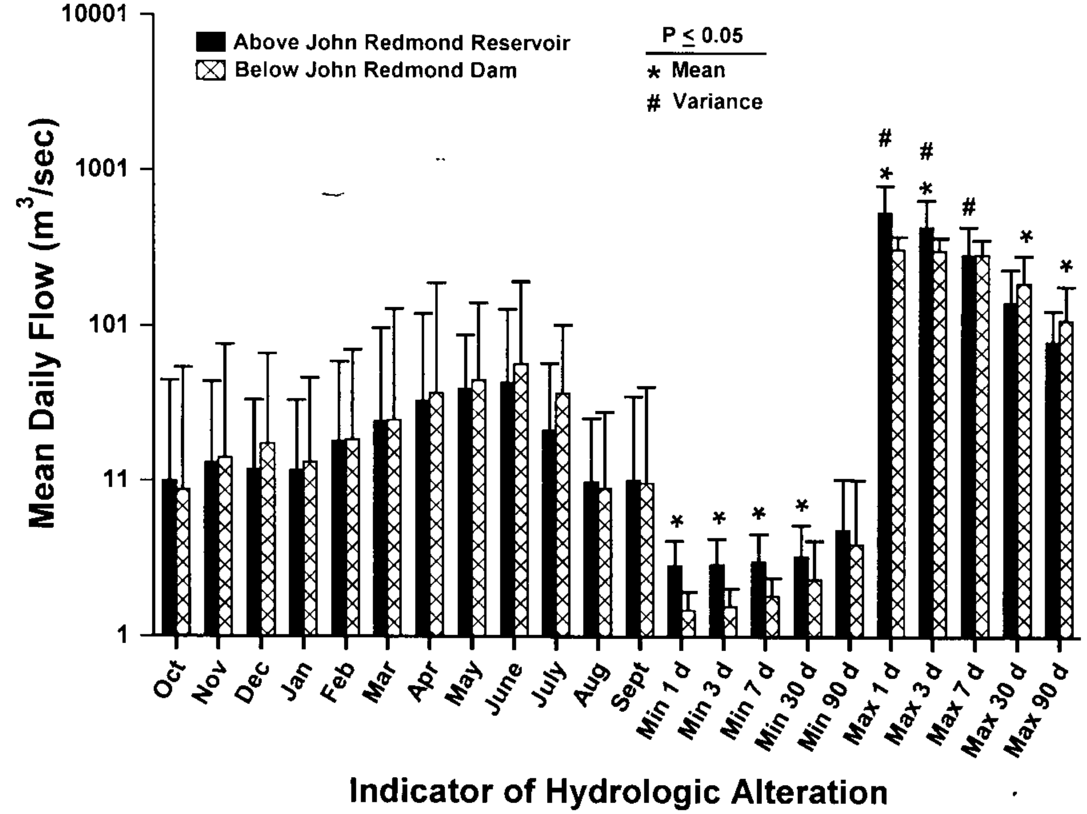

FIGURE 4.—Means and standard deviations for 22 flow indicators above John Redmond Reservoir and below John Redmond Dam (Richter et al. 1996). The U.S. Geological Survey hydrologic data used are from 1970 to 1989 ($N = 20$). The Neosho River hydrograph above the reservoir is represented by combined data from the gauges near Americus and Plymouth, Kansas; that below is represented by the gauge near Burlington, Kansas (see Figure 1). Asterisks indicates significant ($P \leq 0.05$) differences between indicators above the reservoir and the corresponding indicators below the dam; pound signs indicate significant differences in variance. "Min" and "max" refer to minimum and maximum, respectively.

servations of previous researchers (e.g., Cross and Moss 1987). As suspended solids are deposited on the reservoir bottom due to decreases in stream flow, turbidity levels decline and the composition of the substrate changes below the dam (Baxter 1985). The higher fredle index below the dam than above the reservoir represents a shift to the predominance of larger gravel below the dam, a statistic that is supported by the higher (though not significant) geometric mean and percent makeup for two of the three upper size-classes of substrate (Table 2). This increased coarseness of the substrate is a common effect of reservoirs (Baxter 1985). Decreased turbidity and increased substrate size were identified as habitat factors limiting Neosho madtom populations in the Spring River (Wildhaber et al. 2000). This suggests that similar limiting effects on Neosho madtom populations may be occurring below John Redmond Dam as a result of changes in turbidity and substrate size.

Although water temperature, dissolved oxygen, alkalinity, NH_3, and PO_4 differed above John Redmond Reservoir and below John Redmond Dam, it is unclear whether these factors could be limiting ictalurid populations, especially Neosho madtom populations, because nothing is known about the effects of these factors on Neosho madtoms. Mean temperatures above the reservoir and below the dam differed by nearly 3°C; however, nothing is known about the preferred temperature or optimal temperature for growth for Neosho madtoms. Mean dissolved oxygen levels differed by less than 1 mg/L and were greater than levels shown to affect the behavior of other plains fishes (e.g., Bryan et al. 1984). The mean alkalinity level was only 10% less below the dam than above the reservoir

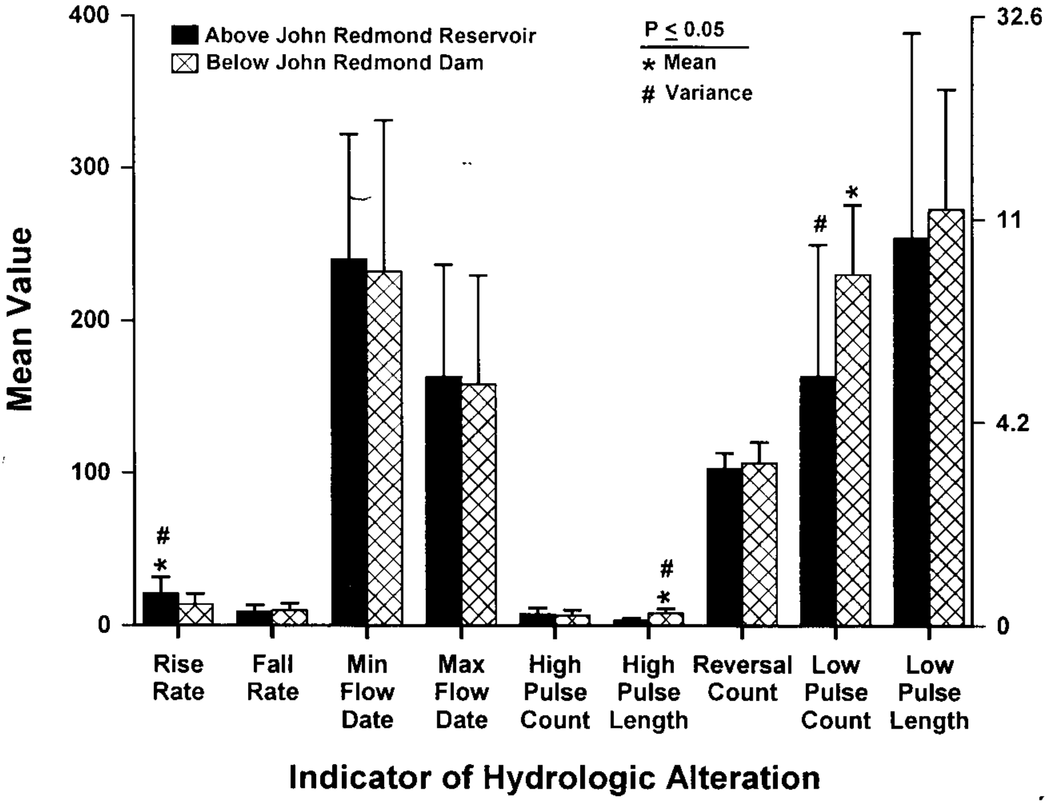

FIGURE 5.—Means and standard deviations for the frequency, duration, and timing of extreme flows as well as the frequency and magnitude of changes in flow rate above John Redmond Reservoir and below John Redmond Dam (Richter et al. 1996). The U.S. Geological Survey hydrologic data used are from 1970 to 1989 (N = 20). The Neosho River hydrograph above the reservoir is represented by combined data from the gauges near Americus and Plymouth, Kansas; that below is represented by the gauge near Burlington, Kansas (see Figure 1). Asterisks indicate significant ($P \leq 0.05$) differences between indicators above the reservoir and the corresponding indicators below the dam; pound signs indicate significant differences in variance. "Min" and "Max" refer to minimum and maximum, respectively. The right axis only applies to low pulse count and low pulse length.

and in both cases was well within acceptable limits for aquatic life (USEPA 1986). Mean NH_3 levels were below the USEPA water quality criteria for chronic toxicity to warmwater species (USEPA 1986). The phosphorus levels that would have been present as a result of the observed mean PO_4 levels above the reservoir and below the dam were greater than recommended levels (USEPA 1986).

Along with removal of particulates, the presence of John Redmond Dam and John Redmond Reservoir has resulted in lower minimum flows, lower short-term (1-d and 3-d) maximum flows, increased occurrence of low-flow events, much less variability in flow rates, increased winter flows, increased long-term (30-d and 90-d) maximum flows, increased length and variability in length of high-flow events, and a later and more variable date of maximum annual flow below the dam. In essence, the Neosho River below John Redmond Dam has become a river with lower minimum flows and lower short-term and higher long-term maximum flows. The lower minimum flows are probably the result of a need to maintain water levels in the reservoir. The lower short-term and higher long-term maximum flows are probably the result of managing the reservoir to minimize downstream flooding.

Lower minimum flows below John Redmond Dam may directly constrain the available area of riffle habitat suitable for Neosho madtoms and therefore represent a limiting factor for such populations in the Neosho River. Neosho madtoms are almost entirely collected on gravel riffles with moderate flows (Fuselier and Edds 1994). Our observed negative correlations between depth and the densities of Neosho madtoms, all other catfishes

TABLE 3.—Coefficients and P-values from two-way analysis of covariance (ANCOVA) of Neosho madtom densities and flow-rate (IHA) measures. The two-way model included year, location relative to John Redmond Reservoir, and their interaction. The ANCOVAs were done with indicators of hydrological alteration (IHA) data from both the current and the preceding water years in which Neosho madtom densities were collected. Each water year extended from 1 October of the previous calendar year to 30 September of the current calendar year. Above John Redmond Reservoir and below the confluence of the Neosho and Cottonwood rivers, IHA values were based on the combined data from the gauges at Plymouth and Americus, Kansas (Figure 1). Neosho madtom densities were grouped and averaged for each year by the nearest U.S. Geological Survey stream gauge (N = 28).

Measure	Coefficient from preceding water year (P)	Coefficient from current water year (P)
Monthly discharge (m^3/sec)		
Oct	0.75 (0.053)	1.66 (0.0081)
Nov	0.61 (0.13)	0.85 (0.14)
Dec	0.93 (0.034)	0.59 (0.22)
Jan	0.84 (0.048)	0.60 (0.17)
Feb	0.69 (0.092)	0.65 (0.12)
Mar	0.99 (0.069)	0.64 (0.15)
Apr	0.44 (0.39)	0.44 (0.24)
May	0.75 (0.16)	0.83 (0.049)
Jun	0.60 (0.17)	0.94 (0.0093)
Jul	0.56 (0.24)	0.91 (0.06)
Aug	1.03 (0.031)	0.89 (0.047)
Sep	0.75 (0.081)	0.60 (0.073)
Magnitude and duration of annual extremes (m^3/sec)		
1-d minimum	0.61 (0.048)	0.76 (0.016)
1-d maximum	0.69 (0.25)	0.50 (0.14)
3-d minimum	0.79 (0.023)	0.98 (0.0057)
3-d maximum	0.45 (0.40)	0.46 (0.17)
7-d minimum	0.84 (0.023)	1.12 (0.0031)
7-d maximum	0.38 (0.51)	0.42 (0.24)
30-d minimum	0.70 (0.066)	1.41 (0.0022)
30-d maximum	0.74 (0.25)	0.57 (0.17)
90-d minimum	0.95 (0.064)	0.94 (0.010)
90-d maximum	0.80 (0.21)	0.68 (0.12)
Timing of annual extremes (day of the year)		
Annual minimum	0.01 (0.011)	0.00092 (0.78)
Annual maximum	0.0057 (0.16)	0.002 (0.64)
Rate and frequency of change in conditions		
Fall rate (m^3/sec)	−0.00012 (0.85)	−0.00018 (0.80)
Rise rate (m^3/sec)	0.46 (0.44)	0.18 (0.39)
Number of reversals between rising and falling discharges	0.013 (0.23)	0.00096 (0.88)
Frequency and duration of low and high pulses		
Low-pulse length (d)	0.08 (0.86)	−0.14 (0.74)
Low-pulse count	−0.55 (0.32)	−0.48 (0.36)
High-pulse length (d)	−0.02 (0.75)	−0.20 (0.86)
High-pulse count	0.02 (0.60)	0.01 (0.86)

combined, channel catfish, and stonecats and the positive correlations between velocity and Neosho madtom and stonecat densities support the observation that depth and velocity are important determinants of habitat quality for Neosho madtoms and other catfishes in the Neosho River basin (Moss 1983; Fuselier and Edds 1994). Based on these observations, we suggest that the lower post-dam low flows downstream from the dam limit availability of suitable habitat for Neosho madtoms, a phenomenon that has been observed for fishes in other systems that have been altered by dams (e.g., Aadland 1993). Further support for the need to increase minimum flows downstream of John Redmond Dam is given by Kinsolving and Bain (1993), who documented recovery of riverine fishes along a disturbance gradient downstream of a hydroelectric dam, and Travnichek et al. (1995), who found that initiation of a minimum-flow regime below the same dam increased the number

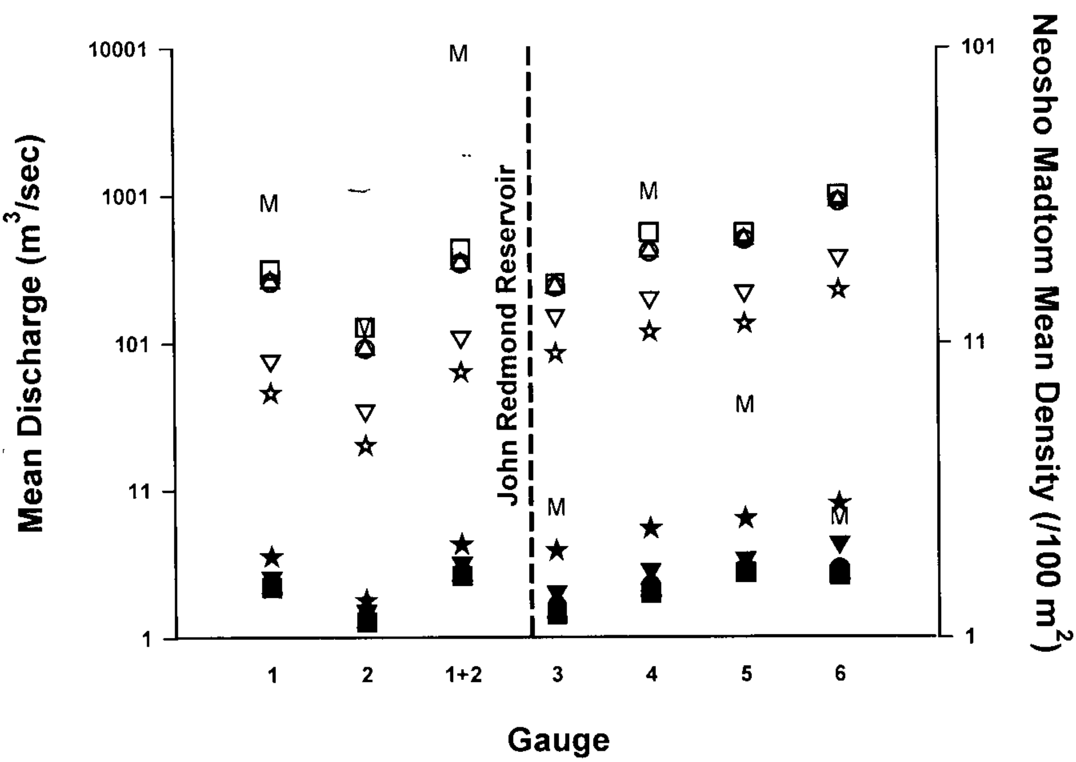

FIGURE 6.—Mean values for minimum (solid symbols) and maximum (open symbols) flow measures and mean annual density of Neosho madtoms (M) at gravel bars nearest a given gauge for each U.S. Geological Survey gauging station for water years 1990–1998. The symbols represent the following time intervals: squares, 1 d; upward triangles, 3 d; circles, 7 d; downward triangles, 30 d; and stars, 90 d. The gauges are ordered from upstream to downstream as follows (see Figure 1): 1 = Plymouth, Kansas; 2 = Americus, Kansas; 3 = Burlington, Kansas; 4 = Iola, Kansas; 5 = Parsons, Kansas; and 6 = Commerce, Oklahoma.

of riverine fish species collected 3 km downstream of the dam. Travnichek et al. (1995) found that the impact on the fish community was greater at the most upstream site below the dam.

The combination of lower minimum flows and lower short-term maximum flow is also likely to indirectly limit the available area of riffle habitat that is suitable for Neosho madtoms by increasing consolidation of gravel bars. Though the substrate is coarser below John Redmond Dam, as indicated by the fredle index and substrate size distribution, it still contains a moderate amount of fine materials (<2 mm; Table 2). It is these finer sediments that allow for the "cementation" of gravel bars during low-water periods that has been hypothesized as a potential limiting factor for Neosho madtoms (Deacon 1961; Moss 1981). Deacon (1961) demonstrated a negative relationship between Neosho madtom abundance and drought. Deacon (1961) and Moss (1981) hypothesized that the drying of organic matter during drought results in the cementing together of the gravel that composes bars normally occupied by Neosho madtoms. In support of the cementation argument, Cross and Moss (1987) documented a change in the substrate from loose and "quick" to firm and stable in the lower Kansas River after construction of an extensive reservoir system. Moss (1981) further suggests that the compaction and cementation of gravel bars, which occurs during periods of low water, hinders recovery of the gravel substrate to the loose consistency preferred by Neosho madtoms that was present before drying. Bulger (1999) hypothesized that the periods of low water resulting in cementation of gravel bar sediments would tend to exclude Neosho madtoms from the interstitial spaces and the habitat in which they are predominantly found (Wenke et al. 1992; Fuselier and Edds 1994). Furthermore, this cementation of gravel during low-water periods would increase bar stability and thus increase the flows necessary to unconsolidate the gravel (Gordon et al. 1992).

Therefore, the lower short-term maximum flows that now occur in the Neosho River below John Redmond Dam probably limit the ability of the river to reverse the consolidation of gravel that occurs as a result of drying during low-water flows.

Our results suggest that minimum flows and their timing are critical for the reproductive success of Neosho madtoms. The USFWS (1991) suggested that certain minimum flows and the timing of the spring rise may be critical to successful reproduction of the Neosho madtom. The positive relationship that we observed between Neosho madtom densities and average daily flows in May and June supports the hypothesis that timing of the spring rise in water may be critical for successful reproduction of the Neosho madtom.

The relationships between Neosho madtom density and average daily flow during August, October, December, and January suggest that minimum flows may be critical to overwinter survival of Neosho madtoms. Previous research has indicated that a larger body size (Miranda and Hubbard 1994a; Smith and Griffith 1994) and the presence of shelter (Miranda and Hubbard 1994b; Quinn and Peterson 1996) increased overwinter survival for fish species such as largemouth bass *Micropterus salmoides*, rainbow trout *Oncorhynchus mykiss*, and coho salmon *Oncorhynchus kisutch*. It may be that inadequate flows just prior to and during the overwintering period affect Neosho madtom populations by limiting habitat resources and thereby decreasing their chance for overwinter survival. The positive relationship between annual minimum flow date and Neosho madtom densities suggests that delaying minimum flows until after population recruitment in the fall may also enhance Neosho madtom population numbers. Increased minimum flows would provide more habitat for the Neosho madtom (a fluvial specialist), especially in the form of shallow edge habitat over gravel bars.

The lower Neosho madtom densities that were observed downstream from John Redmond Dam do not reflect a natural longitudinal gradient in the species' abundance. Even though the Neosho River increases in size and the hydrologic patterns recover to levels more like those above the reservoir, Neosho madtom densities do not exhibit parallel recovery (Figure 6). Past (Moss 1983) and present data appear to show that densities of Neosho madtoms can be as high below the dam as above the reservoir, with no evident longitudinal gradient below the dam (Figure 6). These observations further support the contention that Neosho madtom densities below John Redmond Dam are at least partially the result of direct and indirect effects of dam operation that occur far downstream.

The alterations in water quality and habitat that occur simultaneously with changes in hydrology as the result of damming may be as important as the changes in hydrology themselves in impacting fish communities (Cross and Moss 1987; Patton and Hubert 1993). Our results suggest that, along with the changes in water flow, changes in water quality and habitat may be negatively affecting Neosho madtom populations below John Redmond Dam. Unfortunately, our water quality and habitat measurements were limited to the first year of fish collection and thus precluded more complex analyses that would have allowed us to better determine the effect of water quality and habitat alterations on Neosho River ictalurid populations. The importance of water quality and habitat to Neosho madtom populations has been previously documented (Moss 1983; Fuselier and Edds 1995; Wildhaber et al. 2000).

Changes in hydrology, habitat, or water quality that increase Neosho madtom populations will probably increase the populations of other riffle-dwelling benthic fishes. The strong positive relationships between Neosho madtom densities and those of all other catfishes combined, channel catfish, and stonecats suggest that the status of the Neosho madtom may be an indicator of environmental impacts on all the benthic fish communities of the Neosho and Cottonwood rivers. Previous studies of environmental impacts on Neosho madtom populations (Wildhaber et al. 1999, 2000) have shown positive relationships between the densities of Neosho madtoms, channel catfish, and other riffle-dwelling benthic fishes, such as darters. The Neosho madtom is a better indicator species for the Neosho River benthic fish community than other, more abundant species because it seems to be more sensitive to environmental impacts (Fuselier and Edds 1994; Wildhaber et al. 2000) as a result of its habitat specificity and short life cycle (Moss 1983; Fuselier and Edds 1994). This sensitivity and the ease with which Neosho madtoms can be collected in reasonable numbers (Figure 6) suggest that the status of Neosho madtom populations would provide an effective early-warning system for environmental impacts that may affect the rest of the Neosho River fish community.

Further research is needed to directly test the implications of our findings for habitat and water management strategies within the Neosho River basin. Monitoring of Neosho madtom and other ictalurid populations and physical habitat should continue for the next 3–5 years. Concurrently, flows should be increased below John Redmond Dam so that the flows at Burlington, Kansas, mirror the combined flows at Plymouth and Americus to assess if fish populations and habitat respond to changes in flow as predicted by this study. Further, age and growth information on the widely distributed stonecat should also be collected as a surrogate to Neosho madtom age and growth information owing to the positive relationship between Neosho madtom and stonecat densities that we observed. Because turbidity limits visual observations in the field, laboratory tests are needed to determine if and how flow affects the reproductive behavior and success of Neosho madtoms. Because substrate composition seems to be a critical limiting factor for Neosho madtoms (Moss 1983; Fuselier and Edds 1995; Wildhaber et al. 2000), field studies are needed that test the impacts of habitat alterations, such as gravel mining, on Neosho madtom populations. Implementation of these recommendations, along with those resulting from further research, should lead to a high probability of recovery for Neosho madtom populations in the Neosho River to the levels identified as necessary for delisting of the species as threatened (USFWS 1991).

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References

Aadland, L. P. 1993. Stream habitat types: their fish assemblages and relationship to flow. North American Journal of Fisheries Management 13:790–806.

Bain, M. B., J. T. Finn, and H. E. Booke. 1988. Streamflow regulation and fish community structure. Ecology 69:382–392.

Baxter, R. M. 1985. Environmental effects of reservoirs. Pages 1–26 *in* D. Gunnison, editor. Microbial processes in reservoirs. Dr. W. Junk, Dordrecht, The Netherlands.

Bryan, J. D., L. G. Hill, and W. H. Neill. 1984. Interdependence of acute temperature preference and respiration in the plains minnow. Transactions of the American Fisheries Society 113:557–562.

Bulger, A. G. 1999. Population structure, habitat use, and breeding behavior of the Neosho madtom, *Noturus placidus*. Master's thesis. Emporia State University, Emporia, Kansas.

Cross, F. B., and M. Braasch. 1969. Qualitative changes in the fish-fauna of the upper Neosho River system, 1952–1967. Transactions of the Kansas Academy of Science 71:350–360.

Cross, F. B., and J. T. Collins. 1995. Fishes in Kansas, 2nd edition. University Press of Kansas, Public Education Series, Lawrence.

Cross, F. B., and R. E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. Pages 155–165 *in* W. J. Matthews and D. C. Heins, editors. Community and evolutionary ecology of North American stream fishes, 1st edition. University of Oklahoma, Norman.

Deacon, J. E. 1961. Fish populations, following a drought, in the Neosho and Marais des Cynges rivers in Kansas. University of Kansas publications of the Museum of Natural History 13:359–427.

Fuselier, L., and D. R. Edds. 1994. Seasonal variation in habitat use by the Neosho madtom (Teleostei: Ictaluridae: *Noturus placidus*). Southwestern Naturalist 39:217–223.

Fuselier, L., and D. R. Edds. 1995. An artificial riffle as restored habitat for the threatened Neosho madtom. North American Journal of Fisheries Management 15:499–503.

Gordon, N. D., T. A. McMahon, and B. L. Finlayson. 1992. Stream hydrology: an introduction for ecologists. Wiley, Chichester, West Sussex, UK.

Hesse, L. W., and G. E. Mestl. 1993. An alternative hydrograph for the Missouri River based on the precontrol condition. North American Journal of Fisheries Management 13:360–366.

Kinsolving, A. D., and M. B. Bain. 1993. Fish assemblage recovery along a riverine disturbance gradient. Ecological Applications 3:531–544.

Luttrell, G. R., R. D. Larson, W. J. Stark, N. A. Ashbaugh, A. A. Echelle, and A. V. Zale. 1992. Status and distribution of the Neosho madtom (*Noturus placidus*) in Oklahoma. Proceedings of the Oklahoma Academy of Science 1992 72:5–6.

McMahon, T. E., A. V. Zale, and D. J. Orth. 1996. Aquatic habitat measurements. Pages 83–120 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Milliken, G. G., and D. E. Johnson. 1984. Analysis of messy data, volume I: designed experiments. Wadsworth, Belmont, California.

Miranda, L. E., and W. D. Hubbard. 1994a. Length-dependent winter survival and lipid consumption of age-0 largemouth bass in Bay Springs Reservoir, Mississippi. Transactions of the American Fisheries Society 123:80–87.

Miranda, L. E., and W. D. Hubbard. 1994b. Winter survival of age-0 largemouth bass relative to size, predators, and shelter. North American Journal of Fisheries Management 14:790–796.

Moss, R. E. 1981. Life history information for the Neosho madtom (*Noturus placidus*). Kansas Department of Wildlife and Parks, Final Report 38, Pratt.

Moss, R. E. 1983. Microhabitat selection in Neosho River riffles. Doctoral dissertation. University of Kansas, Lawrence.

Nature Conservancy. 1997. Indicators of hydrologic alteration. Nature Conservancy and Smythe Scientific Software, Haydon, Colorado.

Niemi, G. J., P. DeVore, N. Detenbeck, D. Taylor, A. Lima, J. Pastor, J. D. Yount, and R. J. Naiman. 1990. Overview of case studies on recovery of aquatic systems from disturbance. Environmental Management 14:571–587.

Obeng, L. E. 1981. Man's impact on tropical rivers. Pages 265–288 *in* M. A. Lock and D. D. Williams, editors. Perspectives in running water ecology. Plenum, New York.

Patton, T. M., and W. A. Hubert. 1993. Reservoirs on a Great Plains stream affect downstream habitat and fish assemblages. Journal of Freshwater Ecology 8: 279–285.

Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. U.S. Forest Service, Intermountain Forest and Range Experiment Station, U.S. Forest Service Technical Report INT-138, Denver.

Poff, N. L., D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience 47:769–784.

Putnam, J. E., D. L. Laccock, D. R. Schneider, M. D. Carlson, and B. J. Dague. 1996. Water resource data, Kansas, Water Year 1996. U.S. Geological Survey, Water Resources Division, Water-Data Report KS-96–1, Lawrence, Kansas.

Quinn, T. P., and N. P. Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon (*Oncorhynchus kisutch*) in Big Beef Creek, Washington. Canadian Journal of Fisheries and Aquatic Sciences 53:1555–1564.

Richter, B. D., J. V. Baumgartner, J. Powell, and D. P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10:1163–1174.

Richter, B. D., J. V. Baumgartner, R. Wigington, and D. P. Braun. 1997. How much water does a river need? Freshwater Biology 37:231–249.

SAS Institute. 1990. SAS procedures guide, volume 6, 2nd edition. SAS Institute, Cary, North Carolina.

Scheidegger, K. J., and M. B. Bain. 1995. Larval fish distribution and microhabitat use in free-flowing and regulated rivers. Copeia 1995:125–135.

Smith, R. W., and J. S. Griffith. 1994. Survival of rainbow trout during their first winter in the Henrys Fork of the Snake River, Idaho. Transactions of the American Fisheries Society 123:747–756.

Sparks, R. E. 1992. Risks of altering the hydrologic regime of large rivers. Pages 119–152 *in* J. Carins, Jr., B. R. Niederlehner, and D. R. Orvos, editors. Predicting ecosystem risk: advances in modern environmental toxicology, volume 20. Princeton Scientific Publishing, Princeton, New Jersey.

Stanford, J. A., J. V. Ward, W. J. Liss, C. A. Fissell, R. N. Williams, J. A. Lichatowich, and C. C. Coutant. 1996. A general protocol for restoration of regulated rivers. Regulated Rivers Research and Management 12:391–413.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and procedures of statistics—a biometrical approach, 2nd edition. McGraw-Hill, New York.

Stewart-Oaten, A., J. R. Bence, and C. W. Osenberg. 1992. Assessing effects of unreplicated perturbations: no simple solution. Ecology 73:1396–1404.

Taylor, W. R. 1969. A revision of the catfish genus *Noturus* Rafinesque, with an analysis of higher groups in the Ictaluridae. Smithsonian Institution Press, U.S. Museum Bulletin 282, Washington, D.C.

Travnichek, V. H., M. B. Bain, and M. J. Maceina. 1995. Recovery of a warmwater fish assemblage after the initiation of a minimum-flow release downstream from a hydroelectric dam. Transactions of the American Fisheries Society 124:836–844.

Tulsa District USACE (U.S. Army Corps of Engineers). 1993. Tulsa District civil works projects pertinent data. Tulsa District USACE, Tulsa, Oklahoma.

USEPA (U.S. Environmental Protection Agency). 1986. Ambient water quality criteria. USEPA 440/5–86–001, Washington, D.C.

USFWS (U.S. Fish and Wildlife Service). 1991. Neosho madtom recovery plan. USFWS, Denver.

Wenke, T. L., M. E. Eberle, G. W. Ernsting, and W. J. Stark. 1992. Winter collections of the Neosho madtom (*Noturus placidus*). Southwestern Naturalist 37: 330–333.

Wildhaber, M. L., A. L. Allert, and C. J. Schmitt. 1999. Potential effects of interspecific competition on Neosho madtoms (*Noturus placidus*) populations. Journal of Freshwater Ecology 14:19–30.

Wildhaber, M. L., A. L. Allert, C. J. Schmitt, V. M. Tabor, D. Mulhern, K. L. Powell, and S. P. Sowa.

2000. Natural and anthropogenic influences on the distribution of the threatened Neosho madtom in a Midwestern warmwater stream. Transactions of the American Fisheries Society 129:243–261.

Wilkinson, C., D. R. Edds, J. Dorlac, M. L. Wildhaber, C. J. Schmitt, and A. Allert. 1996. Neosho madtom distribution and abundance in the Spring River. Southwestern Naturalist 41:78–81.

Yount, J. D., and G. J. Niemi. 1990. Recovery of lotic communities and ecosystem from disturbance—a narrative review of case studies. Environmental Management 14:547–569.